View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by HAL Clermont Université

Discharge with liquid non-metallic electrodes in air at atmospheric pressure

Pascal André, Yu Barinov, Géraldine Faure, V. Kaplan, André Lefort, V. Rozdestvensky, Sergey Shkol'Nik

To cite this version:

Pascal André, Yu Barinov, Géraldine Faure, V. Kaplan, André Lefort, et al.. Discharge with liquid non-metallic electrodes in air at atmospheric pressure. P. Fauchais J. Amouroux. Discharge with liquid non-metallic electrodes in air at atmospheric pressure, 1999, France. Begell house, pp.847-852, 1999. <hal-00019602>

HAL Id: hal-00019602

https://hal.archives-ouvertes.fr/hal-00019602

Submitted on 1 Mar 2006

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

DISCHARGE WITH LIQUID NONMETALLIC ELECTRODES IN AIR AT ATMOSPHERIC PRESSURE

P.Andre[*], *Yu.Barinov*[**], *G.Faure*[*], *V.Kaplan*[**], *A.Lefort*[*], *V.Rozdestvensky*[**], *S.Shkol'nik*[**]

* LAEPT. CNRS URA 828. Univ. Blaise Pascal. 24, Av. des Landais, Clermont-Ferrand - France
** A.F.Ioffe Phys.-Techn. Inst. Rus. Acad. Sci., Politechnicheskaya 26, St.-Petersburg 194021 - Russia

ABSTRACT

A d.c. discharge which burning in open air between two flows of tap water is investigated. It appears that the discharge can be operated steady in a diffuse mode at a relatively high voltage and a low current density. Plasma parameters in the interelectrode gap are measured by means of electric probe, spectroscopic and microwave emission absorption techniques. A comparison with a theoretical calculation shows that discharge plasma is far from the thermal equilibrium and allows to determine a plasma composition. The results obtained shows that this discharge can be used for a monitoring of technical and waste water, an analysis and cleaning of waste gas flows.

1. INTRODUCTION

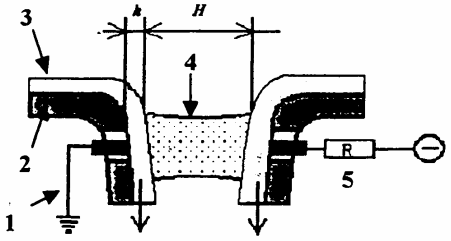
The discharge with liquid nonmetallic electrodes (DLNME) can be realized in d.c. mode in open air between a surface of reservoir with liquid (or a flow of liquid) and metallic electrode, between two flows of liquid, between porous electrodes etc. It is possible to use different kinds of electrolytes and simply tap water. DLNME has unique properties, which are different from those of discharges with high conductivity electrodes (metals). It is self-maintained discharge, which keeps the volumetric (diffuse) form even at atmospheric pressure. DLNME was known more than hundred years but until now it is not perfectly understood. The published results concern the discharge with one liquid electrode [1]. Plasma parameters have not been adequately explored with two liquid electrodes. The interest in investigations of DLNME is stimulated by opportunities of its technical use and, in particular, of its use for a monitoring of technical and waste water, an analysis and cleaning (biological contamination) of waste gas flows [2]. The present work aims at an experimental and theoretical investigation of plasma parameters of DLNME with electrodes from tap water. Some preliminary results were published in [2, 3].

2. EXPERIMENTAL SET-UP AND TEST CONDITIONS

The discharge is produced between two flows of tap water in open air (fig. 1). Metallic current carrying buses is inserted into water flows through insulating plates. One bus is grounded. A voltage is applied to another one via ballast resistor in series. The thickness of water layers h (water electrodes) covering the metallic buses must be thick in order to prevent a breakdown of water and erosion spot formation on buses.

The distance between surfaces of water electrodes is 1.5 cm. ($H \approx 0.7$ cm and $h \approx 0.4$ cm). The voltage applied to metal buses is U=(2.9÷3.1) kV through a ballast resistor of R=10 kΩ . The

discharge is ignited by breaking of a contact bus which shorted the water surfaces. The presented measurements are carried out at I=(50÷60) mA.



1- metallic current carrying buses
2- insulating plates
3- flows of tap water
4- discharge plasma
5- ballast resistor

Figure 1. The cross section of discharge assembly.

3. EXPERIMENTAL RESULTS

3.1 Probe measurements. The cylindrical probe (∅ 0.3mm *l*=1mm) enters into the discharge during a short time. The axial dependence of probe floating potential V_f is shown in figure 2. An example of probe volt-ampere characteristic (VAC) measured in a central region of discharge is shown in figure 3.

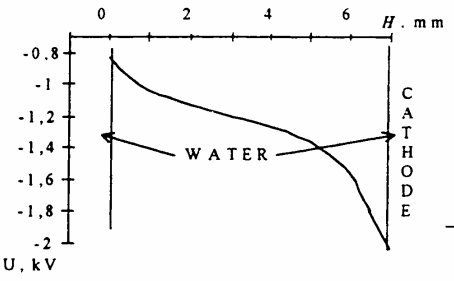


Figure 2. Plasma potential distribution

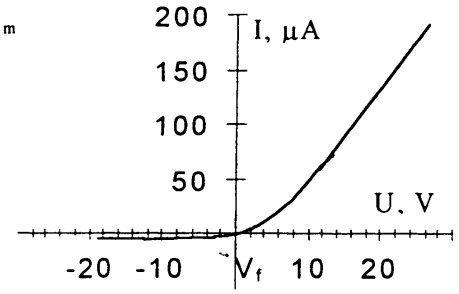


Figure 3. Probe volt-ampere characteristic

Analysis of probe characteristic shows that current transfer in discharge is provided by electrons. This result is in agreement with calculations of plasma composition (see 4. Discussion) according to which the density of negative ions is negligible and the carriers of the negative charge are electrons, and positive charge by NO^+. The estimation of a recombination length of NO^- gives: $L_r \approx 10^{-3}$cm<<a (a - probe radius). Therefore, when an electron current is collected, the main contribution to a difference between a plasma potential V_{pl} and a probe potential V_p is made by undisturbed plasma area [2, 4]. In this case at $V_p > V_f$ VAC should be linear [4] as observed in experiment. The theory [4] allows to determine a plasma conductivity from a linear plot of VAC and a plasma potential V_{pl}.

The estimations in agreement with [4] shows that in our conditions $V_{pl} \approx V_f$ within accuracy of about a few Volts. Thus, the distribution of plasma potential, shown in figure 2, allows to determine an electrical field strength in the gap. Thus, the electric field strength rises toward the electrodes and ranges up to E≈4 kV/cm near the cathode and E≈2 kV/cm near the anode. There is a relatively extent region with approximately constant electric field strength E≈0.7 kV/cm near the middle of the gap. In this region the electron density n_e values are estimated with the measurement results of VAC linear plots. In so doing the measurements of

gas temperature in discharge (see 3.3 Spectr. measur.) were used to determine the electrons mobility values. Taking into account the experimental errors and uncertainty of values of parameters which are used to treat the probe measurements we obtain an estimation for n_e on the discharge axis in the middle-gap region: $(4 \cdot 10^{11} < n_e < 6 \cdot 10^{11})$ cm^{-3}.

The determination of n_e by means of electric probe technique in the atmospheric pressure plasmas is not sufficiently advanced. So, it must be corroborate with an another noncontact, undisturbing technique. An analysis of potentialities of alternative plasma diagnostics tools force us to choose the MicroWave (MW) technique although the use of this technique presents a challenge in experiment conditions under consideration.

3.2 MW emission absorption measurements. The results of probe and spectroscopic measurements provides a possibility to estimate the characteristic frequencies in discharge plasma. The *e-m* collisions frequency ν far exceeds that of *e-e* collisions and is around 10^2 GHz. Plasma frequency f can run as high as 10 GHz. To provide a high enough space resolution and to satisfy the conditions of 'open space technique' feasibility [5], it is necessary to use a sounding MW emission at a wavelength λ of 10^{-1} cm. Thus a frequency F of sounding MW emission will be almost two orders of magnitude higher than f. For a such ratio of frequencies the absorption of MW emission in plasma appears so weak that its measurement is technically rather complex. A use of the resonator technique ensuring a higher sensitivity is hindered by the discharge assembly design. So, it was decided to use an emission at $\lambda \approx 1$cm. In this case a relative value of absorbed MW power α should make some percents. To confine the MW power in area occupied by plasma, a two-wire transmission line was used. The difficulties of such experiments only allow to obtain a mean value of n_e in the middle of the gap.

The measurements at a discharge current I = 60 mA have shown that $\alpha=(5.6\pm0.4)\%$ at F=29.6 GHz and $\alpha=(3.3\pm0.3)\%$ at F=35.2 GHz. To determine a mean n_e value it is necessary to know ν and a size L of the absorbing plasma volume. Calculations for various ν values in the range of $100<\nu<200$ GHz show that the uncertainty in value of ν results in an error of n_e less than 30%. Imperfect knowledge of the plasma size, estimated from spectroscopic measurements (fig.4), gives approximately the same contribution to the error. Taking into account all the sources of errors listed above, we obtain: $(3 \cdot 10^{11} < n_e < 7 \cdot 10^{11})$ cm^{-3}. The result obtained is in a satisfactory agreement with results of probe measurements.

3.3 Spectroscopic measurements. The emissions spectrum of discharge was measured within interval (250-900)nm with the spectrum resolution $\approx$0.15nm. The longitudinal space resolution was $\leq$0.5mm. In the spectrum the molecular bands of N_2 (2+ system), N_2^+ and OH, and also spectral lines of H, O atoms and of metal impurities contained in water were observed. The axial and radial distributions of emission intensities of different species were measured. In fig.4 the radial distributions of N_2 band head (λ=380.4 nm) emission are shown at different axial positions.

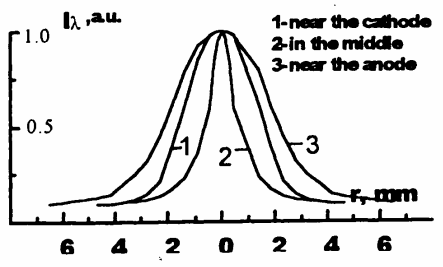


Figure 4. Radial distributions of N_2 band

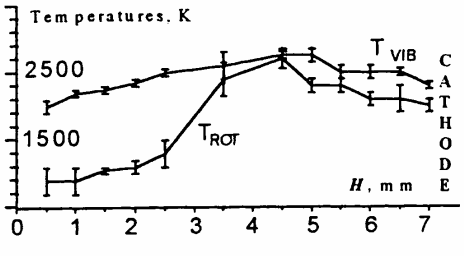


Figure 5. Axial distribution of T_{vib} and T_{rot}

The 2+ system of the N_2 (Δv= -2) was used to obtain the information on rotational and vibrational distribution functions of electronically excited states of molecules. Boltzmann plot method cannot be applied to determine the rotational temperature from the (0-2) band of the 2+ system of N_2. As a matter of fact, it is very difficult to measure the line intensities because of the structure of these spectra. For the other bands the measurement is hampered by overlapping branches. Moreover, the experimental spectral resolution does not allow the use of Boltzmann plot. To determine the rotational and vibrational temperatures of the $C^3\Pi_u$ state of N_2, we make a comparison of experimental spectra with calculated spectra. It is necessary to simulate the 2+ system of N_2 and especially the sequence (Δv= -2) [3]. The results are presented in figure 5.

4. DISCUSSION

From the vibrational and rotational temperatures data (fig.5) we can determine two zones. In the first zone $T_{vib} = 2T_{rot}$ and in the second one $T_{vib} = T_{rot}$. From the Gibbs free energy minimization [6] we can determine the concentration versus the heavy species temperature; we have made two hypotheses:

$$\begin{cases} T_{tr\,e^-} = T_{ex}^{at} = T_{ex}^{diat} = \theta\, T_{tr\,h} \\ T_{vib} = 2\, T_{tr\,h}; \quad T_{rot} = T_{tr\,h} \end{cases}$$

$$\begin{cases} T_{tr\,e^-} = T_{ex}^{at} = T_{ex}^{diat} = \theta\, T_{tr\,h} \\ T_{vib} = T_{tr\,h}; T_{rot} = T_{tr\,h} \end{cases}$$

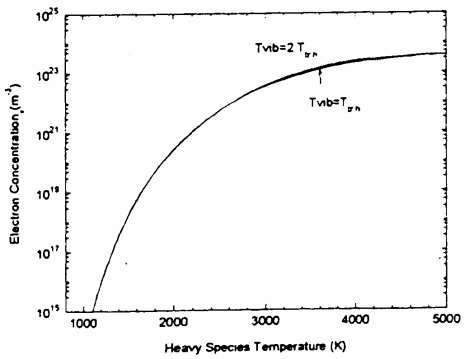


Figure 6. Air 99%, water 1%, θ=3

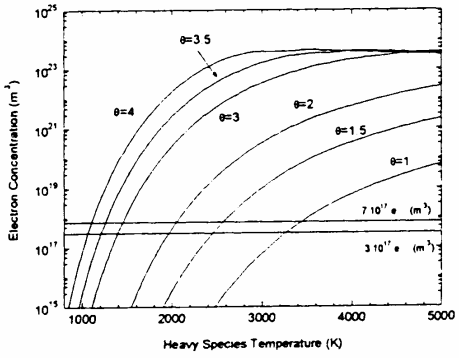


Figure 7. Air 99%, water 1%, θ - parameter

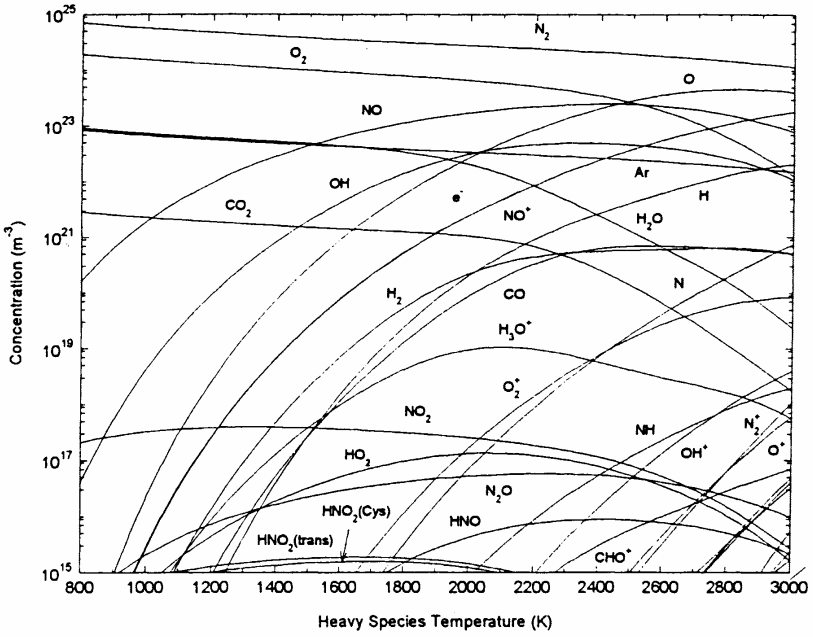


Figure 8. First zone : $T_{tr\,e^-} = T_{ex}^{at} = T_{ex}^{diat} = 3.5\,T_{tr\,h}$; $T_{vib} = 2\,T_{tr\,h}$; $T_{rot} = T_{tr\,h}$

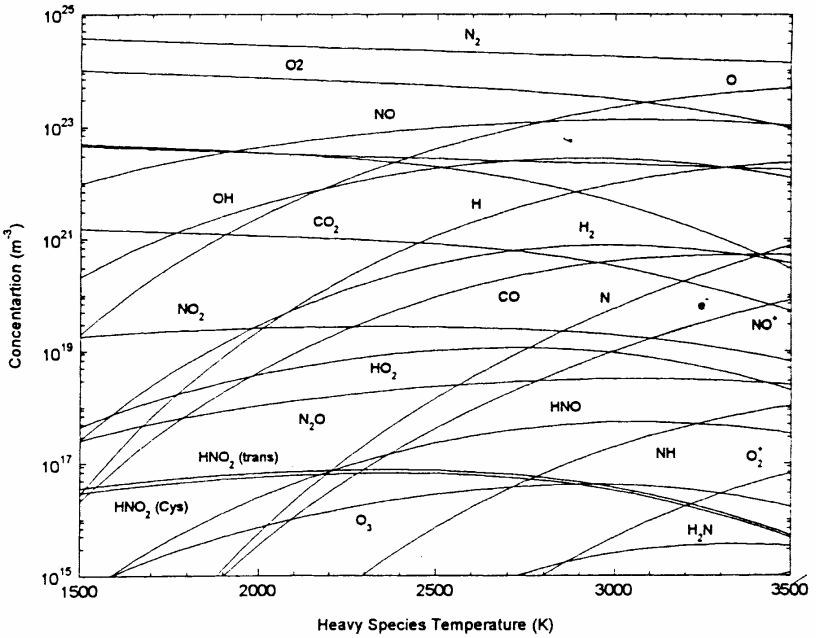


Figure 9. Second zone : $T_{vib} = T_{tr\,h}$; $T_{rot} = T_{tr\,h}$; $T_{tr\,e^-} = T_{ex}^{at} = T_{ex}^{diat} = 1.5\,T_{tr\,h}$

In figure 6, we show the electronic concentration with both hypotheses at thermal non equilibrium θ=3. We observed that the vibrational temperature had no influence on electronic concentration. So, we can calculate the plasma composition to determine the thermal non equilibrium. We can determine θ value using the results of probe and MW emission absorption measurements. In fig.7 we show n_e values versus heavy species temperature for several θ. In the first zone, near the anode, θ is about 3.5 (heavy species temperature T≈ 1100 K), and in the second zone, near the cathode, θ is about 1.5 (heavy species temperature T≈ 2300 K). We have to notice that even with a factor of ten in the measured n_e, we obtained the same θ value.

In figures 8 and 9, we show the concentration obtained for a plasma composed of 99% of air and 1% of H_2O. We can see that the charge neutrality is made between electrons and NO^+.

5. CONCLUSIONS

The study carried out allowed us to obtain an information on parameters and composition of plasma. It was revealed that DLMNE plasma was not uniform and far from thermal equilibrium. In the middle-gap region E/p is about 10 Td. Close to the anode E/p rises up to 20 Td and close to the cathode - up to 80 Td. The results obtained show that DLNME has good prospects to use for a monitoring of technical and waste water, an analysis and cleaning of waste gas flows.

REFERENCES

[1] Gaysin F.M. Son E.E., Electrophysical processes in discharges with solid and liquid electrodes, Sverdlovsk, Russia, Ural Univ. Publ. , 1989, p 432 (in Russian).

[2] Afanas'ev V.P., Andre P., Barinov Yu.A., Faure G., Kaplan V.B., Lefort A., Shkol'nik S.M., Theoretical and experimental investigation of a discharge with liquid nonmetallic electrodes in air at atmospheric pressure, XXIII International Conference on Phenomena in Ionized Gases, vol. III, 1997, pp 104-105, Toulouse, France, Ed. MC Bordage and A Gleizes (Les Ulis, France : EDP Sciences)

[3] Faure G. and Shkol'nik S.M. Determination of rotational and vibrational temperatures in a discharge with liquid non-metallic electrodes in air at atmospheric pressure, Journal Physics D: Applied Physics vol. 31, 1998, pp 1212-1218.

[4] Benilov M.S. The theory of electric probe in a low ionized high pressure plasma flows, High Themperature, vol. 26, 1988, pp 993-1004.

[5] Golant V.E. Microwave technique of plasma investigations, 'Nauka', Publ., Moscow, 1968, p 328 (in Russian).

[6] Andre P. Partition Function and Concentrations in Plasma out of Thermal Equilibrium, IEEE, Transaction on Plasma Science, vol. 23, 3, 1995, pp 453-458.